Objective: To quantify the perfusion of forehead flaps and compare blood flow from the supratrochlear artery with vascular in-growth at the recipient bed.

Methods: Patients with nasal defects necessitating forehead flap closure were prospectively enrolled to study flap perfusion dynamics. Laser-assisted indocyanine green angiography was used to obtain the measurements. When possible, patients returned for weekly recording of flap perfusion from the recipient bed with the pedicle clamped. Analysis of the data was performed using SPY-Q software.

Results: Six patients were prospectively enrolled. All patients had intraoperative angiography at flap transfer, pedicle division, and at least 1 postoperative visit between these surgical procedures. Flow was measured as a percentage of perfusion of normal surrounding tissue. A higher percentage of perfusion was seen at the distal end of the flap when compared with the pedicle when the pedicle was clamped. This phenomenon was seen as early as the 1-week postoperative visit.

Conclusions: This is the first study attempting to quantify forehead flap perfusion from the supratrochlear artery and recipient bed. Data obtained suggest evidence of vascular in-growth 1 week following flap transfer.
study participation was obtained from all subjects in the prospective cohort. Inclusion criteria were all nasal defects requiring forehead flap reconstruction for which laser-assisted angiography data were available. Patients with iodine allergies and severe hepatic dysfunction were excluded from analysis. The patient’s insurance provided coverage for use of the imaging device intraoperatively.

**INDOCYANINE GREEN**

Indocyanine green (ICG) (IC-GREEN; Akorn Inc) is a water soluble, tricarbocyanine dye used in medical diagnostics. Its uses are well-established in measuring cardiac output, hepatic function, and ophthalmic angiography. Following intravenous (IV) administration, ICG binds tightly to plasma proteins and is confined to the intravascular system. This property makes ICG an ideal tracer for measuring vascular perfusion.

Absorption and fluorescence of ICG occur in the near-infrared range with maximums of 805 nm and 835 nm, respectively. These values are near the isosbestic point of hemoglobin and oxyhemoglobin, natural chromophores that affect the fluorescence of fluorescein. This allows deeper penetration of the skin with fluorescence induced from blood vessels within the deep dermal plexus and subcutaneous fat.

An additional benefit of ICG is its pharmacokinetic properties. It has a short half-life of 3 to 4 minutes, allowing multiple doses and recordings without saturation of fluorescence. Consequently, previous administration does not prevent the detection of microvascular compromise. Clearance occurs rapidly and almost exclusively in the bile. Indocyanine green used for injection contains sodium iodide and should be used cautiously in this patient population. Anaphylactic reactions have been reported.

**LASER ANGIOGRAPHY**

Patients with nasal defects necessitating forehead flap coverage had intraoperative perfusion mapping of the pedicled flap with laser-assisted ICG angiography using the SPY imaging system (LifeCell). This device is approved by the US Food and Drug Administration for real-time intraoperative determination of vascularity and perfusion of soft tissue. It has been used successfully in cardiac surgery to evaluate patency of coronary artery bypass grafts. The device is safe and easy to use and has reproducible results. Images were obtained of the forehead vasculature prior to pedicle elevation as well as of the pedicle and recipient bed immediately following flap transfer. At the second-stage pedicle division, additional imaging was performed following flap inset. Analysis of the data was performed using SPY-Q software (LifeCell). In regions of interest, as defined by the investigators, the percentage of fluorescence was calculated relative to normally perfused tissue in the periphery. The SPY-Q software used an algorithm to set the normal peripheral tissue at 100% perfusion and reported flap perfusion as a percentage of this reference.

Patients were asked to return for weekly follow-up visits, when perfusion mapping of the pedicle and recipient bed was performed using the SPY imaging system based on a standardized protocol. A peripheral IV catheter was placed, and the patient was transferred to a darkened room. A 20 French red rubber catheter was placed around the base of the pedicle and clamped with a tonsil clamp until blanching was noted on either side of the catheter overlying the pedicle. Through the IV catheter, 7.5 mg of ICG was injected with a 10-ml bolus of normal saline. Real-time laser-assisted ICG angiography was performed for 60 seconds. The peripheral IV catheter was removed, and the patient was discharged in stable condition.

**RESULTS**

A total of 6 forehead flaps were followed up prospectively with weekly analysis of flow, when possible. Three patients completed weekly measurements that occurred on postoperative day 7, 14, and 21. The other 3 patients had measurements performed on postoperative day 7 dur-

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Abbreviation: Post-op, postoperative.

*a* µ% Represents the average of 4 measurements taken of the flow in that portion of the flap distal to the clamped site. *σ* Denotes the standard deviation of that measurement. Flow is calculated by the SPY-Q software (LifeCell) as a percentage of flow in the area of interest relative to a predetermined area of flow of 100% in normal peripheral tissue.

*b* Patients 4 through 6 did not participate in the 2- and 3-week post-op visits.
ing their postoperative visit for suture and staple removal. These 3 patients were unable to return for additional recordings owing to financial and travel constraints.

All patients had intraoperative perfusion mapping during forehead flap transfer and subsequent pedicle division (postoperative day 28).

The Table outlines the mean percentage (µ%) and standard deviation (σ) of flow for each flap. Four measurements were taken along the mid-portion of the pedicle over the supratrochlear artery, which represents the primary perfusion of the flap when the pedicle is unclamped. Four additional measurements were recorded from the distal aspect of the flap. Each mean percentage recorded is relative to a background flow of 100% perfusion in normal peripheral tissue as determined by SPY-Q software. All measurements were obtained while the pedicle was clamped to determine the contribution of flow solely from the recipient bed.

With the exception of patient 1 at the 1-week postoperative visit, all patients demonstrated a percentage of flow in the distal portion of the flap equal to or greater than that in the pedicle of the flap when the flap was clamped. An analysis of the flow dynamics of patient 1 at the 1-week postoperative visit clearly demonstrated flow through the pedicle when clamped, indicating inadequate clamping of the pedicle. This accounts for the greater flow seen in the pedicle in this patient at 1 week following flap transfer. The higher percentage of flow in the distal portion of the flap suggests that perfusion of this tissue is from the recipient bed and not the pedicle. Over the 60-second period of measurement, the perfusion extends retrograde to the proximal portion of the flap.

There were no intraoperative or postoperative complications among the study group. Patient 3 was an ac-
tive smoker (1 pack per day). Patients 4 and 5 had low hairlines necessitating a moderate amount of hair bearing skin on the flap. Presence of hair over the area of interest on the flap led to relatively lower recordings of perfusion compared with the other study patients. No adverse reactions to the injection of ICG were noted.

The following cases represent the clinical utility of laser-assisted ICG angiography.

CASE 1: DETERMINING VIABILITY OF QUESTIONABLE TISSUE

This patient served as the index case for interest in quantifying flap perfusion given the postoperative complication. His data were collected prior to development of the prospective cohort outlined in the Table.

The patient was an 81-year-old man who presented with a lesion of the nasal dorsum. A biopsy demonstrated basal cell carcinoma, and he underwent Mohs surgery with a resulting 3.2 × 3.2-cm defect along the right nasal ala and tip with extension along the right medial crus. The defect was full thickness along a 1-cm portion of the alar rim. A forehead scar extending the horizontal length of the forehead 1 to 2 cm below the hairline was noted. The patient stated it was a laceration from a motor vehicle crash approximately 35 years prior to his presentation to our clinic. Intraoperatively, SPY imaging of the forehead was performed (Figure 1). A septal flap, conchal cartilage graft, and forehead flap were used to repair the defect. Clinically, the flap appeared well perfused throughout. At the conclusion of the case, SPY imaging of the transferred flap was performed (Figure 2). A clear demarcation of poorly perfused tissue was noted distal to the scar. Postoperatively, the patient developed epidermolysis of the portion of the flap demonstrating poor perfusion with SPY imaging (Figure 3). Following conservative wound care, this area healed without complication (Figure 4).

CASE 2: EVALUATING FLAP PERFUSION FROM THE RECIPIENT BED

A 51-year-old man presented with a right nasal lesion present for approximately 2 years. He reported an extensive sun exposure and smoking history (1 pack per day for 30 years). A biopsy demonstrated basal cell carcinoma, and he had Mohs resection resulting in a 2.5 × 5.0-cm defect involving the right nasal sidewall and ala. He underwent a forehead flap repair of the defect. SPY imaging was used intraoperatively (Figure 5) as well as at his first postoperative visit (Figure 6). Measurements of flow (patient 5, Table) indicated evidence of recipient bed perfusion of the distal aspect of the flap at the 1-week postoperative visit. He continued to smoke throughout his treatment course despite our recommendation to abstain.

Forehead flaps remain the workhorse of nasal reconstruction and are often the standard for nasal defects larger than 1.5 cm. They provide excellent skin texture and color match. Their robust blood supply is well documented, making it a reliable flap with reproducible results. Partial or full thickness necrosis of the flap are rare complications with rates reported from 1.7% to 5.4%. Most of these complications are observed among smokers. The major drawback of this technique is the amount of time patients typically spend away from work or social activities during the period between primary and secondary surgical procedures. Shortening the time between these procedures would thus be a significant benefit to these patients.

Despite its frequent use in nasal reconstruction, to our knowledge no study exists that quantifies forehead flap perfusion following transfer to the recipient bed. The survivability of a flap after pedicle division would of course depend on a number of factors, such as actual blood flow from the recipient bed, the size (square area) of the flap, status of the recipient bed, and type of reconstruction. For example, purely cutaneous flaps receive blood supply not only from skin edges but presumably from the deep tissue, while major reconstructions that involve free cartilage grafts would receive limited flow from the deep tissue. These variables may make it difficult to apply universal rules for time from primary to secondary surgery. However, imaging such as that presented in this study may provide an avenue for measuring actual flow and determining if it is adequate for pedicle division. To our knowledge, this study represents the first effort to achieve this goal. In the present study, intraoperative and postoperative laser-assisted ICG angiography were used to objectively measure perfusion of forehead flaps. We demonstrated flow in these flaps with the pedicle clamped at...
1 week following flap transfer. Real-time angiography confirmed the distribution of flow from distal to proximal in these clamped flaps. This suggests that significant neovascularization has occurred within 1 week of the transfer. We have not yet determined if this amount of neovascularization is adequate for flap survival independent of the pedicle. We hope that follow-up studies may provide a correlation between observed flow and flap survival.

Case 1 illustrates the clinical utility of real-time intraoperative ICG imaging. Figure 1 clearly demonstrates the scar along the forehead with lack of flow across the scar. When tissue distal to the scar is incorporated in the flap, there is a clear line of demarcation distal to the scar along the distal aspect of the flap (Figure 2). Clinically, this appeared as healthy tissue following flap transfer. Aggressive wound care with antibiotic impregnated emollients was used immediately postoperatively based on the intraoperative imaging even though there was no clinical evidence of flap compromise. At his 1-week postoperative visit, there was clear evidence of epidermolysis, which was managed conservatively with no long-term sequelae. The patient was grateful for our proactive management and ability to predict this complication.

The location of the supratrochlear artery remains consistent at 1.7 to 2.2 cm lateral to the midline as defined by Shumrick and Smith. This area typically corresponds to the medial portion of the brow. Preoperative laser-assisted ICG angiography has the benefit of delineating the origin and course of the supratrochlear artery along the forehead. This area is easily marked by the surgeon prior to flap harvest. In patients with prior forehead trauma or scarring, it can demonstrate evidence of blood flow across the scar. This information may assist the surgeon in identifying the optimal region of harvest providing the highest opportunity for success. In smokers, in whom higher complication rates are expected, real-time angiography can demonstrate flow at the distal aspect of the flap following harvest and prior to transfer. This datum may guide the surgeon’s decision to delay flap transfer.

The temporary social morbidity that accompanies treatment of a defect with a forehead flap may be significant for the patient. Decreasing the time from initial surgery to pedicle division would thus reduce the psychosocial impact of this operation for patients. Consequently, additional studies are needed to quantify flap perfusion on a larger scale and confirm these data. Specifically, determination of the minimal neovascularization required to support the flap could significantly shorten the time to pedicle division.

One of the limitations of this study is its small sample size. A larger series would permit further stratification of patients with medical comorbidities and tobacco use, as well as those with superficial vs full thickness repairs. This information may ultimately assist in customizing a plan for pedicle division rather than applying the 3- to 4-week waiting period between surgical procedures to all patients.
In conclusion, laser-assisted ICG angiography has the potential to assist the surgeon with real-time analysis of perfusion and flap viability. This may lead to improved outcomes in this patient population. Additional studies are necessary to confirm these data and determine the minimum perfusion required for flap success. Once determined, patients may ultimately undergo pedicle division earlier than the currently accepted standard of 3 to 4 weeks.

Figure 6. One-week postoperative visit. Laser-assisted Indocyanine green angiography was performed at 15 (A), 30 (B), 45 (C), and 60 (D) seconds. The pedicle remained clamped throughout the imaging. Bright areas indicate well perfused tissue. SPY-Q software was used to color map at each time interval. In these images, increased intensity indicates areas of increased perfusion. Note the increase in flow at the distal aspect of the flap with increases in time (white arrows). This flow is independent of any blood flow from the pedicle which remains dark while clamped throughout testing. “Fixed baseline: 15” represents the background fluorescence value; fps, frames per second.
REFERENCES